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TESTING FOR HOMOGENEITY IN TEMPERATURE TIME SERIES AT CANADIAN CLIMATE STATIONS

by

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ATMOSPHERIC ENVIRONMENT SERVICE

DOWNSVIEW, ONTARIO

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Abstract

A procedure based on the earlier work of Mitchell (1961) and others for testing for homogeneity in seasonal maximum and minimum temperature time series is described. The method involves comparing a base station time series with a parallel areally representative "reference" series created from selected nearby auxiliary stations. Differences between the two series are computed and the resulting difference series is tested statistically in a 5-year sequential process for equality of means using the student's t-test. T-test values exceeding the 95% critical limits identify statistically and possibly climatologically significant step inhomogeneities in the base series. The series are graphed, station histories examined, and the results of the statistical tests analyzed in light of these, to further assess the climatological significance of the inhomogeneities identified. These three sources of information complement one another in determining possible causes and effects for the inhomogeneities identified, and in assisting to make recommendations regarding data adjustments. A summary report is prepared for each station addressing such factors as station longevity, data completeness, and data homogeneity. The procedure has been partially automated with access to the AES National Climate Data Archive (NCDA) via the Downsview Computing Centre (DCC) mainframe computer system.

Résumé

Une procédure basée sur le travail antérieur fait par Mitchell (1961) et aussi par plusieurs autres pour tester l'homogénéité des séries temporelles des températures maximales et minimales est présentée. Cette méthode consiste à comparer la série de la station de base avec une série de référence créée à partir de stations avoisinantes. La série des différences entre les deux séries précédentes est étudiée. Les moyennes mobiles sur cinq ans sont obtenues et la statistique t est utilisée pour tester l'égalité de deux moyennes consécutives. Les valeurs de t excédant les limites critiques indiquent des changements de niveau dans la série de la station de base. En plus, le rapport historique de cette station est examiné et les activités qui ont pu causé ces changements dans la série sont identifiés. Un rapport est alors produit pour chaque station testée. Il résume les résultats de l'analyse ainsi que certaines recommendations qui peuvent être utilisé pour l'ajustement éventuel des données. Cette procédure a été automatisé et est présentement disponible sur l'ordinateur de Downsview pour analyser les température des archives climatologiques du SEA.

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1. Introduction

Heightened concern about climate variability and climate change is evidenced in the growing number of government policy decisions that are based on a knowledge of climate; in the environmental consciousness exhibited by the public; and in the increasing frequency with which the topic is discussed in the media. Scientists from around the world are now seriously re-examining the databases upon which past climate change scenarios have been based. It is now understood that the results of climate change research, and much of the long-term planning of governments and policy makers, based in part upon this research, are only as realistic and credible as the integrity of the original input databases permit.

National meteorological organizations have long been concerned with the integrity of their climate archives. In spite of on-going, meticulous quality control given to the data at the time of entry into the archives, there are and probably always will be irregularities in the data as stored. Most of the inconsistencies are relatively easy to detect as they often involve unrealistic values and orders of magnitude differences which are clearly visible to even the untrained eye.

Another whole profusion of "error" types are less easily detected, and are a major cause for concern in time series analysis, one of the basic tools in climate change studies. Discontinuities or inhomogeneities in the data series result most frequently from climate observing station relocations from one site to another at various times during the history of the station. Other more elusive causes may be changes in instrumentation at the site; malfunctioning instruments; poorly sited or exposed instrument enclosures; changing observing practices and procedures; the growth of nearby vegetation; the construction of buildings and other structures in the vicinity of the observing site; and vehicular traffic and other manned activity in and around the observing site. Some of these causes result in systematic data errors manifested as continuous or trend changes in the data series while others are detectable as discontinuous, sharp, sudden "jumps" in the series (see Appendices A and B). It is imperative that such errors in the databases be detected and corrected as much as possible thereby improving the quality of the basic data upon which climatic change studies are based. It should be kept in mind, however, that the original archived datasets should never be tampered with and that separate "cleaned" datasets should be produced thus enabling retrieval of the original data if required at some future time.

Numerous methods exist for testing for homogeneity in temperature time series. Most incorporate in some form the early work of J.M. Mitchell Jr. in the United States. The current work has its origins in the earlier investigations and constitutes an adaptation of the basic Mitchell technique to the Canadian situation. The procedure, which is partially automated, appears to work reasonably well for identifying, but not quantifying, step inhomogeneities of statistical significance (some of which are also of climatological significance), in temperature time

series. The following report describes the procedure, its application at two Canadian prairie stations, and the results obtained. Research continues on the development of refined techniques that will lessen the dependence upon surrounding climate stations for comparison purposes and that will permit quantification of the inhomogeneities identified. One of the outcomes of these investigations will be the establishment of an official AES Reference Climate Station Network (RCSN) comprising representative, long-term, continuously-operating climate observing stations strategically located across the country. The work will ultimately form the basis for the production of a Canadian Historical Climate Dataset for use in future climate variability and change studies.

2. Purpose

The purpose of the current work is to expand upon the previous work of Skinner (1987) and Mitchell (1961) and develop and implement an operational, objective, automated, statistically-based method to:

a) test for homogeneity in temperature time series;

b) identify step changes (inhomogeneities) in temperature time series that are of statistical and climatological significance; and

c) recommend on the need for data adjustments where required.

Note: The method described in this report effectively identifies step inhomogeneities only. A refined technique, under development at the time of writing, will be used to more-precisely identify such inhomogeneities and to also identify non-climatic trend inhomogeneities.

3. Data

The data tested are year-month (monthly) mean maximum and minimum temperature series (climate elements 040 and 041) retained in the NCDA for the entire period of record for each station. Only stations with 25 or more years of "continuous" record and preferably only those that are currently in operation are tested. A further processing requirement dictates that there are no gaps of five years or more and that the total number of missing year-month values does not exceed 10% of the total number of values in the record under examination. Documentation about the NCDA may be obtained by consulting the Handbook On Climate Data Sources Of The Atmospheric Environment Service (1988).

4. Method

The following method (Figure 1.0) has been developed to identify step inhomogeneities.

4.1. A "reference" time series consisting of a combination of nearby auxiliary stations is constructed as follows:

4.1.1. Year-month values (monthly) of maximum and minimum temperatures for each auxiliary station are obtained from the NCDA.

4.1.2. Missing year-month values at each auxiliary station are estimated using method A (Appendix C).

4.1.3. The monthly first difference (FD) series for each month and for each auxiliary station is computed (e.g., difference between Jan. 1988 and Jan. 1987, between Jan. 1987 and Jan. 1986, etc.).

4.1.4. The monthly average first difference (AFD) series is computed by averaging the first difference series for all auxiliary stations.

4.1.5. Outliers in the auxiliary series are searched for and removed by comparing the FD of each auxiliary station with the AFD; if any value of the FD series deviates from the corresponding AFD value by more than 9.9°C and a standard deviation of 9.9, then it is deleted and a new AFD value is computed from the remaining FDs. These thresholds are user-defined and are used to remove isolated gross errors, that may exist in the archived data. The NCDA data have undergone stringent quality control at the time of archiving and therefore relatively few of these errors exist.

4.1.6. The reference time series is re-constructed from the "new" AFD using year-month values beginning with the most recent value (1988) at the base station and proceeding backward in time.

4.1.7. Season averages (i.e., winter - Dec, Jan, Feb; spring - Mar, Apr, May; summer - Jun, Jul, Aug; autumn - Sep, Oct, Nov) are computed for the reference series.

4.2. The "base" time series is compared with the "reference" series by computing the difference between the two and applying the student's t-test for the equality of means for successive 5-year intervals along the resulting difference series as follows:

4.2.1. Year-month values (monthly) of maximum and minimum temperatures for the base station are obtained from the NCDA.

4.2.2. Missing year-month values at the base station are estimated using method B (Appendix C).

Figure 1.0 Flow Chart Outlining Details of Method

4.1.1
Obtain year-month max. temp. series for each auxiliary station from NCDA
4.1.2
Estimate missing year-month values at each auxiliary station (Appendix C)
4.1.3
Calculate monthly first difference (FD) series for each auxiliary station
4.1.4
Calculate monthly average first difference (AFD) series for combined auxiliary stations
4.1.5
Delete outliers for each auxiliary FD series and re-calculate AFD series for combined auxiliary stations
4.1.6
Re-construct reference time series from AFD series beginning with base station value for Jan 88 and proceeding back in time
4.1.7
Calculate season averages for reference time series
4.2.1
Obtain year-month max. temp. series for base station from NCDA
4.2.2
Estimate missing year-month values for base station (Appendix C)
4.2.3
Calculate season averages for base time series
4.2.4
Calculate season average difference series (base series - reference series)
4.2.5
Apply student's t-test for equality of means to successive 5-year means along difference series
4.2.6
Record dates when t-values exceed 95% level critical limit

4.2.3. Season averages (i.e., winter - Dec, Jan, Feb; spring -Mar, Apr, May; summer - Jun, Jul, Aug; autumn - Sep, Oct, Nov) are computed for the base series.

4.2.4. The difference between the season average base series and the season average reference series is computed. This is the base-reference (B-A) series.

4.2.5. The student's t-test for equality of means is performed using the "B-A" series and comparing successive 5-year means while omitting the intermediate year (e.g., the mean of B-A for 1901-1905 is compared with the mean of B-A for 1907-1911 and so on).

4.2.6. Dates when t-values exceed the critical limits at the 95% significance level identify step inhomogeneities in the difference series. These are further examined in association with the station history information and with the plotted graphs of the seasonal mean maximum and minimum temperatures for the base and reference series for the period.

5. Operational Procedure

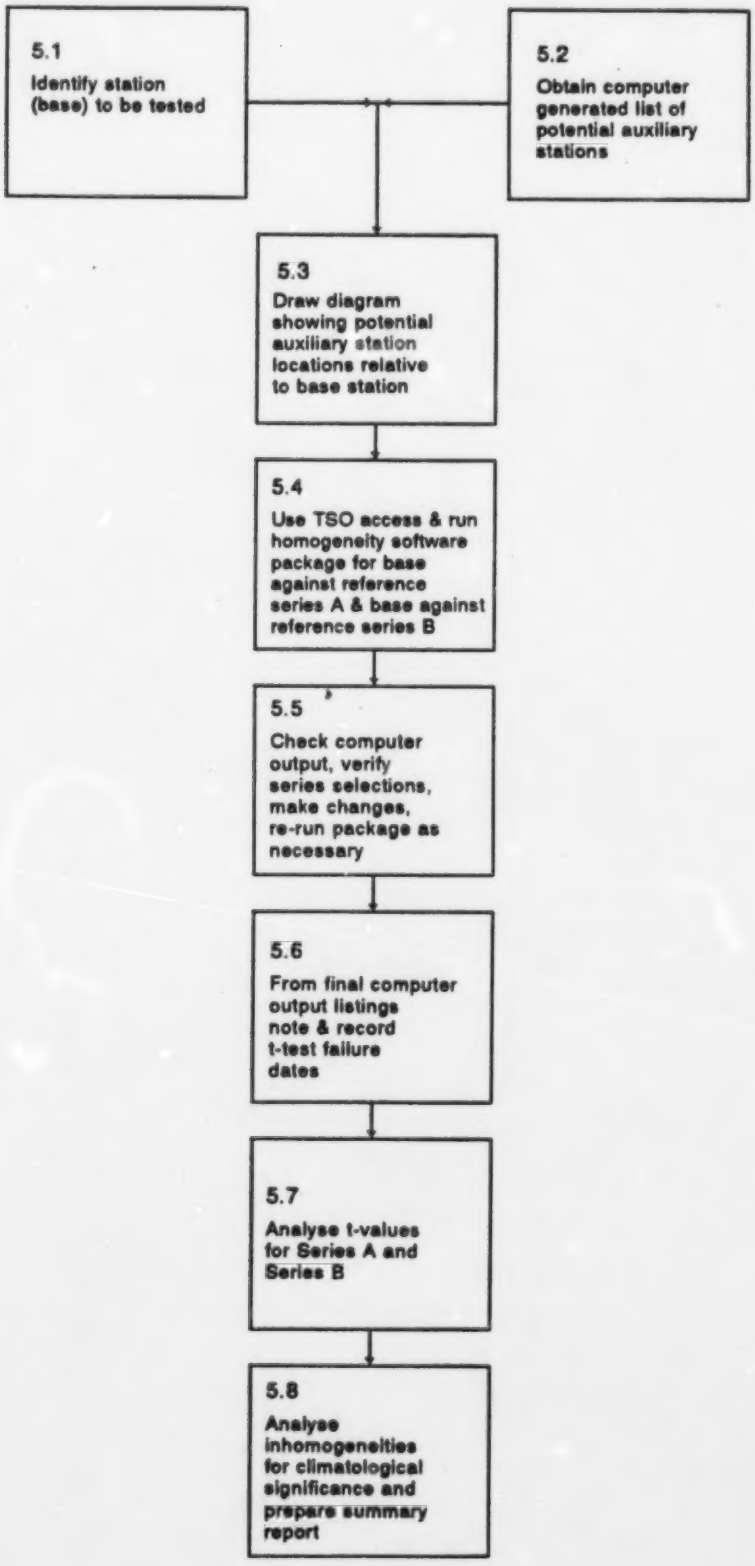
The following procedure (Figure 2.0) has been developed and the homogeneity software package prepared for processing on the DCC mainframe computer system.

5.1. The climate station to be tested is identified by the analyst and is referred to as the base station.

5.2. Through interactive access to the AES Station Information System (SIS), a computer-generated list of auxiliary stations is produced from which two separate reference series may be prepared for comparison with the base. The desired minimum number of years of data overlap with the base and the radial distance to be searched from the base are specified. Defaults in the software are set at 50 years and 100 km respectively but can be, and often must be, changed at the discretion of the analyst. It is desirable to have a minimum of 6 auxiliary stations in total from the same climate regime. More auxiliary stations, as many as 20-30, are preferable to help ensure that the reference series is as representative as possible of the temperature regime of the surrounding geographic area. Inhomogeneities at the auxiliary stations tend to be offset or minimized by the areal averaging process, particularly when a large number of auxiliary stations are used.

5.3. When the list of potential auxiliary stations is obtained, a direction and distance diagram of the auxiliary stations relative to the base station is prepared by the analyst. This diagram is used to assist in preparing two separate reference series, reference series A and

Figure 2.0 Flow Chart Showing Steps in Operational Procedure for Homogeneity Testing Program


5.1
Identify station (base) to be tested
5.2
Obtain computer generated list of potential auxiliary stations
5.3
Draw diagram showing potential auxiliary station locations relative to base station
5.4
Use TSO access & run homogeneity software package for base against reference series A & base against reference series B
5.5
Check computer output, verify series selections, make changes, re-run package as necessary
5.6
From final computer output listings note & record t-test failure dates
5.7
Analyse t-values for Series A and Series B
5.8
Analyse inhomogeneities for climatological significance and prepare summary report

reference series B. The objective is to select auxiliary stations such that the two reference series will be as representative as possible of the temperature regime of the surrounding geographic area.

5.4. The homogeneity software package (TSO menu and FORTRAN program) is accessed and run separately for each reference series. The analyst specifies user-defined criteria such as the base station name and the corresponding 7-digit number, the beginning and ending dates for the base station, the auxiliary stations by number, the type of computer output desired and other house-keeping, JCL-related criteria.

5.5. The output listings are obtained and examined for verification of the reference series, periods of missing data, data overlap, distribution of auxiliary stations around the base, etc. Sometimes it is necessary to redistribute certain auxiliary stations in series A and/or B based on this output. Usually minor modifications are required to the two reference series before running the procedure a second and final time to generate the statistical summary data. Graphics are also requested with the final run.

5.6. The final output listings are obtained for both runs, that is, for the base station against reference series A and the base station against reference series B. The output is examined and the statistical summary data and reference materials are assembled for subsequent analysis.

5.7. The peak t-statistic values for all periods when the t-value exceeded the 95% critical limit are identified. These data are entered by the analyst onto separate charts for each computer run and examined for agreement. If a specific step inhomogeneity occurs in both runs and the base station is the only station common to both, and if the reference series are areally representative of the surrounding region, then the inhomogeneity is likely to be at the base station.

5.8. A subjective assessment of each inhomogeneity identified in the statistical analysis is made in light of the additional information available from the plotted graphs and the station history information and the climatological significance of each is assessed. A summary report is prepared for each station tested and recommendations regarding the need for data adjustments are offered.

6. Statistics

Proceeding sequentially through the "difference" series (base minus reference) from the earliest year to the most recent, successive 5-year season means are computed. These 5-year means with a 1-year intermediate gap are tested for equality using the student's t-test at the 95% significance level. The intermediate year (i.e., 1-year gap) represents the year under test in which a suspected potential step inhomogeneity exists. Since we do not know the precise location of the step change within the season (i.e., beginning, middle, or end), we omit this season (year) from the test period. If the t-value exceeds the 95% critical limit then the null hypothesis is rejected, that is, the hypothesis that the means of the two successive 5-year periods are equal, is rejected, and it is assumed that the means of the two periods are not equal. There is a 5% risk that the null hypothesis will be rejected when it should have been accepted. The t-statistic for the equality of means test assumes that the variances before and after the step change are unknown and are unequal.

It can be written as follows:

test: H_o: $\mu_1 = \mu_2$ vs H_a: $\mu_1 \neq \mu_2$

reject: H_o if $|t| \geq t_{n1+n2-2}(\alpha/2)$

where:

$$t = \frac{(\overline{x_1} - \overline{x_2}) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$\overline{x_1} = \sum \frac{d_{1i}}{n_1}, \quad \overline{x_2} = \sum \frac{d_{2i}}{n_2}$$

$$s_1^2 = \frac{\sum (x_i - \overline{x_1})^2}{n_1 - 1}, \quad s_2^2 = \frac{\sum (x_i - \overline{x_2})^2}{n_2 - 1}$$

$n_1 = n_2 = 5$, $\alpha = 0.05$,

d_{1i} = differences of base minus reference for first 5 years
d_{2i} = differences of base minus reference for second 5 years

It can be seen that if the sample variances are large, then the t-statistic is relatively small. For this reason, when there is a higher amount of variability in the data, as for example, in the winter months at many locations, computed t-values are small and frequently do not exceed the pre-specified critical limits. But when the sample variances are small, the t-statistic is relatively large, and the opposite effect is true. Such is the case in the summer months when variability in the data is usually less at most locations. In this situation the t-statistic is more likely to exceed the critical limit.

Although the procedure is sufficiently sensitive to detect even very small "statistically" significant step changes, it was found that sequences of at least three successive t-values exceeding the 95% critical limit are usually required to distinguish "climatologically" significant step changes.

7. Results

The tests for two stations, Regina A, Saskatchewan and Calgary A, Alberta are summarized in this report for illustrative purposes. The Regina maximum and minimum data were assessed to be homogeneous and the Calgary data were not. Regina and other southern Saskatchewan stations were selected initially for study because of the relatively uniform topography of the area making possible the easy construction of areally representative reference series. This non-complex topography thus played a major role in simplifying the assessment of the effectiveness of the technique.

7.1. Summary for Regina A, Saskatchewan (4016560)

The Regina A station was assessed to be long-term and complete. Observations began at Regina in 1884, long before the 1932 site relocation to the airport. However, the data prior to 1898 were fraught with missing values making them virtually unusable for the period 1884-1897. Both observing sites were and still are located more or less upstream from the Regina "urban" complex which minimizes the urban effect that typically influences the data at large urban centres such as Toronto and Hamilton in eastern Canada. The surrounding topography was and continues to be relatively uniform, gently rolling prairie, open and unobstructed in all directions. The move from the early location at the RCMP site 3.6 km west of the city to the municipal airport a few km southwest of the city had no detectable effect on the maximum and minimum temperature series. Over the years increased activity in and around the airport has led to some concern about the possible effects of aircraft movements and the construction of buildings on the data, however, no major effects were detected.

Two reference series were prepared for comparison with the Regina A datasets. It was determined that a number of non-climatic inhomogeneities were bound to exist at some of the auxiliary stations but it was believed that the averaging process by which the auxiliary stations were combined into the reference series would tend to offset or minimize these. Very large step inhomogeneities had already been removed as part of the routine procedure for construction of the reference series. Also, since two distinctly separate and independent reference series were prepared and compared separately with the base station series, identical inhomogeneities that were identified as a result of both comparisons were likely to be at the base station.

The two reference series used to test the Regina A data were:

Reference Series A	Reference Series B
Humboldt	Caron
Midale	Indian Head CDA
Moose Jaw CHAB	Regina CDA
Muenster	Strasbourg
Semans	Tugaske
Whitewood	Yellow Grass

The statistical tests performed on the 5-year means of the differences between the base and the reference series identified a number of inhomogeneities at the 95% significance level. Most were flagged as exceeding the critical limits for only one or two consecutive test periods (Figures 3.0 and 4.0). These were then checked against the station history file (Appendix D) and against the plotted graphs for maximum temperature (Figures 3.1-3.4), and for minimum temperature (Figures 4.1-4.4). They were assessed to be very small and climatologically insignificant. One somewhat more-pronounced inhomogeneity, at least in terms of statistical significance, occurred in the minimum temperature series in the spring and summer of 1962/63 and in the autumn of 1961 (Figure 4.0). The implication is the occurrence of an inhomogeneity in these seasons in the period 1961 to 1963. The use of season means averaged over 5-year periods makes identification of the precise year by this procedure difficult. Examination of the graphs for these seasons (Figures 4.1-4.4) shows that the changes in the series at these points are very small. These plots of minimum temperature also show signs of probable climatic warming in southern Saskatchewan especially from the mid-1970s onward. Study of this phenomenon is left to subsequent analysis.

Further examination of the station history file for Regina added little revealing information. It was concluded that the step changes identified above were small and although statistically significant at the 95% level, were in fact, climatologically insignificant. At the time of writing this is believed to be the case for Regina A but of course, all results are subject to further assessment.

The Regina A year-month datasets for maximum and minimum temperature were therefore assessed in this analysis to be long-term, complete, and homogeneous. Based on these results the Regina A station would warrant consideration for inclusion in the official Reference Climate Station Network, however, further evaluation and assessment is needed. This could best be carried out locally by AES officials who are intimately familiar with the details of the Regina A site. Land-use changes, urban growth, potential for continued long-term operation of the station, and other factors need to be taken under consideration.

7.2. Summary for Calgary Int'l A, Alberta (3031093)

The Calgary Int'l A datasets were also assessed to be long-term and complete. The station began operation in 1903 and has been operating continuously since that time with no missing year-month maximum and minimum temperature data throughout its history. As the station history file (Appendix E) revealed, however, there were several significant station relocations at various times. Fortunately, most of these were reasonably well documented in the station inspection reports. The more noteworthy relocations were; a move within the town-site in October 1912 with an increase in station elevation of about 12 metres, a second relocation within the town-site in September 1921 with an additional 2 metre increase in elevation, the move to the airport 2.4 km NNE of the city centre in May 1931 (elevation increase of 22 metres), and a move to the "new" airport 7.2 km NNE of the city centre in November 1938 with no change in elevation. There were also a number of instrument site relocations over the years within the airport complex. These were carried out in an effort to maintain adequate site exposures as new buildings were erected at the airport, aircraft activity was increased, and urban growth around the airport perimeter increased. The early station locations prior to the airport locations appear to have been influenced to some extent by "urban" factors even though at the time the city was small and rather rural in nature. Later growth and development at and around the airport locations had a noticeable effect on the data which will be discussed in the following summary.

Two reference series were prepared for comparison with the Calgary Int'l A datasets and seasonal mean maximum and minimum temperature series were plotted (Figures 5.1-5.4 and 6.1-6.4). It was also suspected that some inhomogeneities existed at some of the auxiliary stations but again it was believed that their effects were reduced in the averaging process. For comparison with Calgary, fewer auxiliary stations were available than at Regina since the Rocky Mountain barrier located immediately to the west limited station selection in that direction. The two reference series chosen, therefore, utilized only the minimum number of auxiliary stations considered acceptable for this method. These series comprise the following stations:

Reference Series A	Reference Series B
Gleichen	Hillsdown
Red Deer	High River
Three Hills	Olds

The statistical tests performed as previously described, identified at the 95% significance level, the inhomogeneities listed below. The test results correlated very well with the site information available in the station history file and strong evidence to support the statistical results was found.

Only those step inhomogeneities associated with the maximum temperature series were considered to be both statistically and climatologically significant (Figures 5.0 and 6.0). These are summarized as follows:

Maximum Temperature

spring 1913 1924 1931
summer 1914 1925 1931
autumn 1913 1925 1930 1967

The season maximum temperature series was found to be statistically inhomogeneous in the spring, summer, and autumn of 1913/14, 1924/25, and 1930/31. As before, the dates could not be precisely identified due to the nature of the analysis, however, they were very close to known station relocation dates. Upon examination of the corresponding graphs (Figures 5.1-5.4) it appeared that spring, summer, and autumn maxima between the date of the station relocation within the city in October 1912 and the first move to the airport in May 1931 were too high and in need of some downward adjustment. They appeared to be mostly homogeneous before and after these dates. The 1924/25 dates identified by the statistics test were secondary dates within the overall period 1912-1931 and appeared to be related to the in-town relocation in the early 1920s and possible subsequent site exposure problems. Other inhomogeneities identified by the statistical test were also examined in light of the available station history information and the graphed data, and were assessed to be small and climatologically insignificant.

The Calgary Int'l A year-month datasets for maximum and minimum temperature were assessed in this analysis to be long-term and complete. However, the maximum temperature series was assessed to be not homogeneous and in need of adjustment while the minimum series was homogeneous. Based on these results, the Calgary Int'l A station would not be a good prospect for consideration as an official Reference Climate Station (RCS). Several factors would make it an unlikely candidate; namely, the distinct inhomogeneous period in maximum temperatures between 1912 and 1931 (although these can be adjusted), the location of the station well within the Calgary city suburban complex, the ever-encroaching surrounding urban

development in the vicinity of the station, the increasing development within the airport complex itself, uncertainty about possible discontinuance of or change of the climate observing program, possible changes in observing staff and priorities, and many other considerations.

8. Conclusion

A partially automated mainframe computer-based system is described for testing for homogeneity in maximum and minimum temperature time series at Canadian stations. The method comprises a variation and adaptation of earlier methods developed by Mitchell in the 1960s in the United States and later investigations in Canada by Skinner (1987) and Aston (1987). Its use, like the Mitchell method, is dependent upon the availability of a large selection of nearby climate stations (auxiliary stations) from which to prepare one or more suitable reference series.

The procedure appears to perform reasonably well for identifying statistically and climatologically significant step changes when used subjectively in association with the detailed station history files and graphical displays of the data being tested. It represents a significant improvement over previous methods used in the Canadian Climate Centre to test for homogeneity in time series. It has been expanded to test maximum and minimum temperature time series (previously mean temperatures or ranges only); to test season means (most previous work tested annual means only); to be as "automated" as practical thereby facilitating processing of large numbers of stations; and finally, to be statistically based and as objective as possible.

Recommendations for data adjustment have been offered based on the results of the testing procedure, although no attempt was made in the present study, to adjust the data to correct or remove inhomogeneities. Such work is left to a subsequent undertaking.

The procedure currently in use is partially automated and is somewhat objective, but experience has shown that it is not readily useable without at least some prior familiarity. It is highly recommended that individuals choosing to utilize the package described in this report first consult the authors for clarification and for discussions relating to possible subsequent developments in the field of homogeneity testing.

9. Future Work

Although the procedure described in this report performs reasonably well there continue to be some inherent disadvantages with it. Because of the large volume of data being processed, it has been designed for application to season means as opposed to monthly means. Skinner (1987)

comments that Mitchell believes season means yield better test results than monthly means partly because the error variance of season mean temperatures is only about one-third that of monthly means. However, recent research using monthly means has shown considerable promise and is currently under further investigation. In spite of efforts to automate the current procedure, significant manual intervention continues to be necessary, as for example, in defining and establishing the areal reference series, extracting the station history information, and in charting the results of the statistical tests. Although objective in nature, considerable subjectivity continues to be necessary in the analysis phase when integrating the results of the statistical tests, the station history information, and the graphical displays. The procedure also does not lend itself to quantitative assessment of step inhomogeneities, an essential ingredient before subsequent corrections and adjustments can be determined and applied.

The next version of homogeneity testing software, under development in the CCC at the time of writing, will be designed to overcome, as much as possible, many of these problems. It will be designed to identify, in addition to step inhomogeneities, trend inhomogeneities. It will also have the capability of quantifying discontinuities thereby more easily facilitating subsequent data adjustments. It will be structured such that the necessity of having a large selection of nearby auxiliary stations, as was the case in the current method, will be lessened. And finally, less emphasis on the role played in the analyses by the station history information, will be sought. This is considered necessary because of the general lack of appropriate site details currently contained in the station history files. Research is also continuing into the well recognized problems associated with testing for absolute homogeneity at stations in isolated areas, that is, in areas where few or no nearby auxiliary stations exist. In a northern, sparsely-inhabited nation such as Canada, this continues to be a major concern for climate analysts.

10. References

Atmospheric Environment Service (1988). Handbook On Climate Data Sources Of The Atmospheric Environment Service. Section 6, Climatological Digital Archives, Downsview, Ontario, pp. 6-1 - 6-17.

Aston, D. (1987). Long-Term Stations In Canada. Unpublished summary reports by province, Downsview, Ontario.

Baillargeon, G. and J. Rainville (1977). Statistique appliquée tome 2. Les Editions S M G, Trois-Rivières, Québec, pp. 327-330.

Billingsley, P., D.J. Croft, D.V. Huntsberger and C.J. Watson (1986). Statistical Inference For Management And Economics. Allyn and Bacon, Inc., pp. 301-304.

Karl, T.R., H.F. Diaz and G. Kukla (1988). Urbanization: Its Detection And Effect In The United States Climate Record. Journal Of Climate, American Meteorological Society, Volume 1, November 1988, pp. 1099-1123.

Mitchell, J.M. Jr. (1961). The Measurement of Secular Temperature Change In The Eastern United States. Research Paper No. 43, U.S. Weather Bureau, Washington, D.C., 80 pp.

Skinner, W.R. (1987). An Analysis Of The Homogeneity Of Long-Term Temperature Records From Some Principal Canadian Climatological Stations. Canadian Climate Centre, CCC Report No. 87-9, Downsview, Ontario, 55 pp.

Some Causes of Inhomogeneity

1. Trend Inhomogeneities (gradual changes over time):

   a. sheltering by growth of trees/shrubs and/or by increase in numbers of nearby buildings/structures;

   b. heating by development of industry, aircraft ops., machinery and/or by development of city/urban complex;

   c. deterioration of screen condition (e.g. paint), on-going malfunctioning instrumentation (e.g. faulty thermometers), poor observing practices/procedures.

2. Step Inhomogeneities (sudden changes, possible uniformity thereafter):

   a. move site from/to sheltered, poorly ventilated area;

   b. move site from/to heat source;

   c. repair or replace instruments to correct a problem (e.g. screen repairs, painting, new thermometers), change observer/observing practices (e.g. time of observation);

   d. move site to higher/lower elevation, to area with different ground cover (e.g. pavement, gravel, cultivated, grass, etc.), from poor to better or vice versa, from/to upstream water-body.

Effects On Season Maximum and Minimum Temperatures

1. Trend Inhomogeneities

	Maximum				Minimum			
	win	spr	sum	aut	win	spr	sum	aut
a. sheltering	hi	hi	hi	hi	lo	lo	lo	lo
b. heating (urbanization)	hi	hi	hi	hi	hi	hi	hi	hi
c. poor screen condition	-	hi	hi	hi	-	hi	hi	hi
faulty thermometers	hi or lo in all				hi or lo in all			
observing practices	hi or lo in all				hi or lo in all			

2. Step Inhomogeneities

	Maximum				Minimum			
	win	spr	sum	aut	win	spr	sum	aut
a. move from sheltering	lo	lo	-	lo	lo	lo	lo	lo
move to sheltering	hi	hi	hi	hi	hi	hi	hi	hi
b. move from heat source	lo	lo	lo	lo	lo	lo	lo	lo
move to heat source	hi	hi	hi	hi	hi	hi	hi	hi
c. replace max. therm.	hi or lo in all				-	-	-	-
replace min. therm.	-	-	-	-	hi or lo in all			
change observer	hi or lo in all				hi or lo in all			
change time of obs.	hi or lo in all				hi or lo in all			
d. pavement to grass	-	lo	lo	lo	-	lo	lo	lo
move to higher elev.	-	lo	lo	lo	lo	lo	lo	lo
move to lower elev.	-	hi	hi	hi	-	lo	lo	lo
move to near water	-	lo	lo	hi	-	lo	hi	hi
move from water	-	hi	hi	lo	-	hi	lo	lo

Note: The preceding list is intended to be neither comprehensive nor complete and many variations and opposing causes/effects may exist for similar situations depending on a number of external factors such as scale of event, multiple simultaneous causes, season, and other factors. It is believed that some of the causes/effects listed here are sufficiently fine-scaled as to be undetectable by the analysis methods used in the current project. Urbanization effects have been well documented by many authors and most recently by Karl et al. (1988).

Estimating Year-Month Mean Temperatures

Method A: At The Auxiliary Station

Note: Auxiliary stations are nearby stations which are "combined" to form the reference series. Auxiliary stations must have at least 10 years of data in common with one another.

1. For a missing year-month value at auxiliary station #1 (aux1), compute the "period" mean for aux1 for the years corresponding to overlapping years at aux2; compute the "period" mean for aux2 for the same overlapping years; use the difference between these two means as a correction factor to be added to the "known" year-month value at aux2 to "estimate" the unknown year-month value at aux1.

2. If other auxiliary stations exist with a "known" value corresponding to the missing value at aux1, then repeat the above procedure for each of these "paired" with aux1. After the mean difference between the overlapping years at aux1 and aux2, aux1 and aux3, aux1 and aux4, etc. have been computed, then add each of these differences to the respective "known" value in each series corresponding to the "unknown" value in aux1 (i.e., produce separate estimates for the unknown value in aux1). Finally, sum and average these "estimates" to get the final estimated value for the "unknown" value in aux1.

Method B: At The Base Station

1. For a single missing year-month value use the nearest 10 year-month values (in the same month) on either side of the missing value to compute a mean to "replace" the missing value.

2. For a sequence of missing year-month values use the nearest 10 year-month values on either side of the first missing value to compute a mean to "replace" the first missing value in the sequence. Then use the nearest 10 year-month values on either side of the second missing value (excluding the value just estimated) to compute a mean to "replace" the second missing value in the original sequence. Repeat the process as necessary to complete the series.

Station History File For Regina

Historical details for Regina, Saskatchewan (4016560) as extracted from the Station History Files of the Data Management Division, Canadian Climate Centre.

Date	Site Changes and Notes
1884-1932	Observations by RCMP at barracks 3.6 km W of city centre
1932	Regina flying club became official observers
Sept. 8, 1932	Station at municipal airport, screen 12.2 m S of gas station, 42.7 m S of Regina Municipal Hangar, E of landing strip, screen in good condition
July 23/24, 1934	Land rises 182.9 m S of screen, city of Regina is NE of airport
1937	Full-time weather observing station established by Met. Service
June 19, 1939	New administration building under construction, new met. instruments to be supplied upon completion
May 3/4, 1943	Screen and rain gauge to be moved SE of admin. building, new site will be N of taxi strip, 2 Stevenson screens in use
April 30, 1956	Screen in good condition, good screen exposure 36.6 m SE of admin. building
June 7, 1963	Map shows met. instruments enclosed in 61 m x 61 m area, parking lot to SE
Dec. 2, 1971	Airport has 2 runways and 4 hangars, instrument area has 3 Stevenson screens
May 1972	Met. office located at terminal building 3.2 km SW of residential area of city, surrounding land is flat and cultivated
Nov. 23, 1977	3 Stevenson screens re-set in ground to correct 10° tilt caused by soil shifting toward a trenched and loosely back-filled area of some years previous

Dec. 16, 1982	Instrument exposure fair but has been deteriorating over past 3 years, more buildings and parking lots added, new met. instruments at new location scheduled for July 1983
Sept. 14, 1983	New met. instruments installed at new location, exposure is good to excellent
March 22, 1984	Instrument site exposure will deteriorate when terminal and weather services building is completed, large amounts of surrounding pavement will continue heat island problem as before
Feb. 28, 1985	Met. instruments in fenced, grassed area 35 m SE of new airport operations building, occasional "propwash" from taxiing aircraft, snow from snow removal vehicles, and large amounts of dark pavement are problems

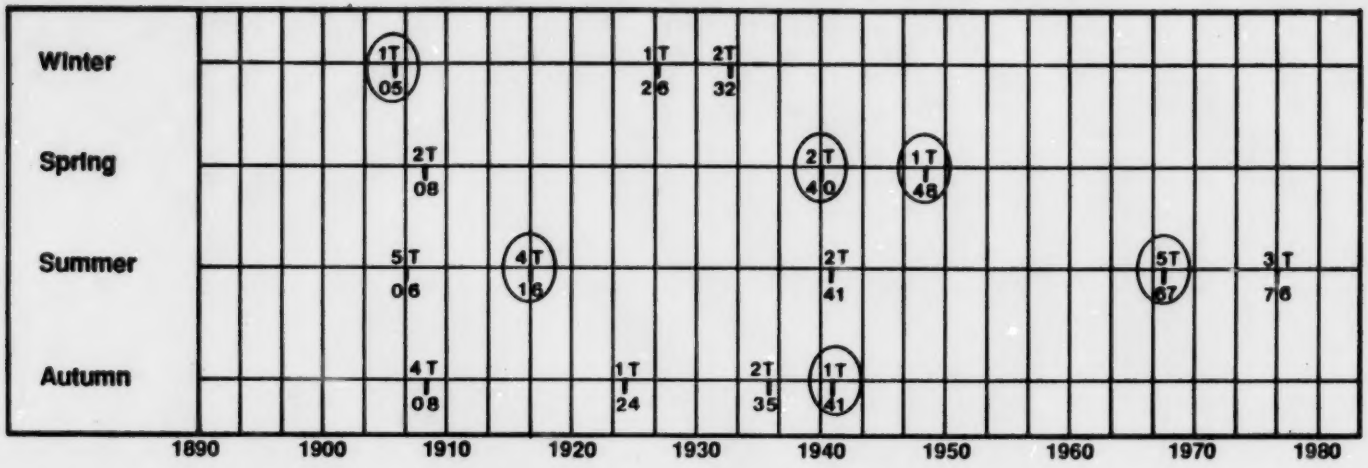
Station History File For Calgary

Historical details for Calgary, Alberta (3031093) as extracted from the Station History Files of the Data Management Division, Canadian Climate Centre.

Date	Site Changes and Notes
1884-1911	Site located in Calgary city, 1044 m elevation
Oct. 1912	Station relocation within city, 1056 m elevation
Sept. 1921	Station relocation within city, 2 blocks N & 5 blocks W of former site, 1058 m elevation
May 1931	Station relocation to municipal airport 2.4 km NNE of city centre, 1079 m elevation
Sept. 11, 1934	Screen 10.4 m SE of met. office, 10.4 m NE of hangar, W of gravel road & flying field, screen in good condition
June 9/10, 1935	Met. equipment unchanged from 1934 & in excellent condition
Nov. 11/28, 1938	Station relocation to "new" TCA airport 7.2 km NNE of city centre, elevation 1084 m
Aug. 11/17, 1939	Present location of met. instruments is poor & relocation is planned for soon
Sept. 5, 1941	Screen is 12.2 m SW of 4.6 m high building, W of gravel road, W of air force buildings, SW of pavement area and hangar, SE of parked snow removal equipment, exposure is only fair due to proximity of buildings and frequent construction activity
Mar. 24, 1948	Further met. instrument site deterioration due to proximity of buildings
May 26/31, 1949	Met. instrument site still poorly exposed due to asphalt, buildings, vehicular traffic
June 7/11, 1950	Further met. instrument site deterioration, summer maximum temps. may be high due to proximity of ramp
April 11/14, 1953	Met. instrument site exposure only fair due buildings, pavement, vehicular traffic
March 1, 1956	Met. instrument site relocation within airport complex, screens moved away from buildings & tarmack, elevation 1084 m

May 1968	Met. instrument site relocation within airport complex, screens 213.4 m N terminal building, elevation 1084 m
1972	Extensive urban growth around airport, airport in NE quadrant of city, urban pollution & heat island effect
1973	Met. instrument site relocation within airport complex, elevation 1090 m
June 1985	New Stevenson screens installed in met. instrument compound

Maximum Temperature for Regina and Reference Series A



Maximum Temperature for Regina and Reference Series B

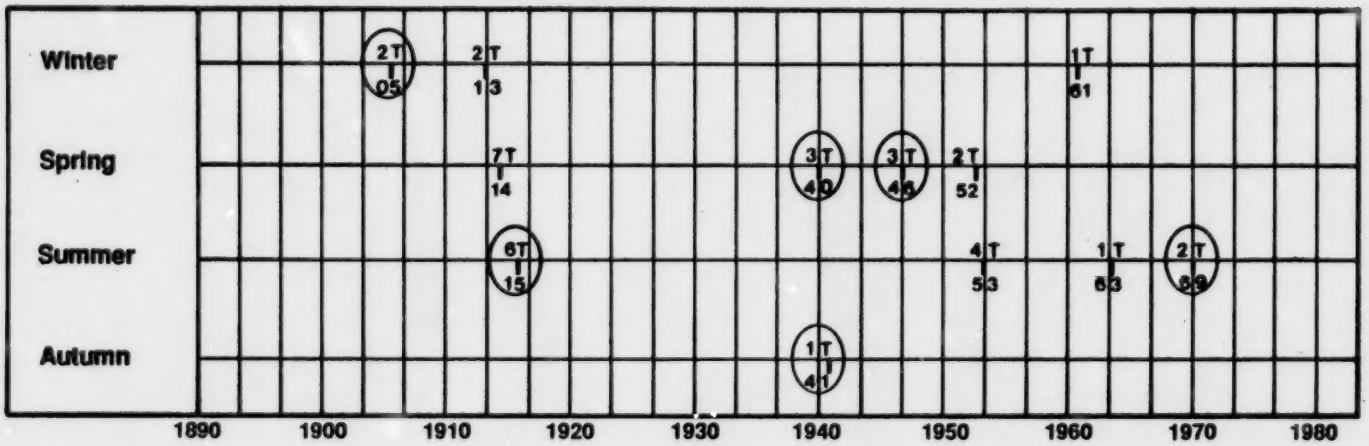


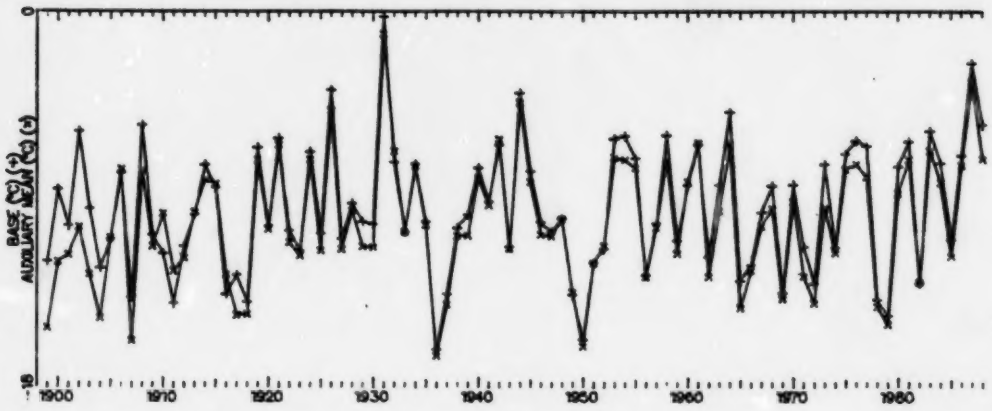
Figure 3.0 Years Identified by T-Value Exceeding the 95% Critical Limit

Notes:

1. Circled years represent "failed" test results common to both the A and B computer runs and year shown is the year in which the peak t-value occurred (e.g., 40 represents peak t-value in 1940)

2. Consecutive "failed" test results are shown above the year in which the peak t-value occurred (e.g., 2T represents two consecutive "failed" tests (i.e., two consecutive years)).

REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1898 TO 1988

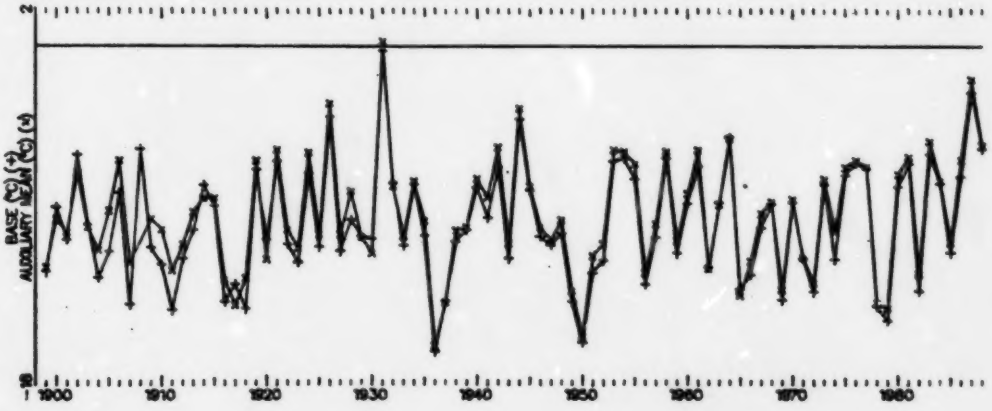
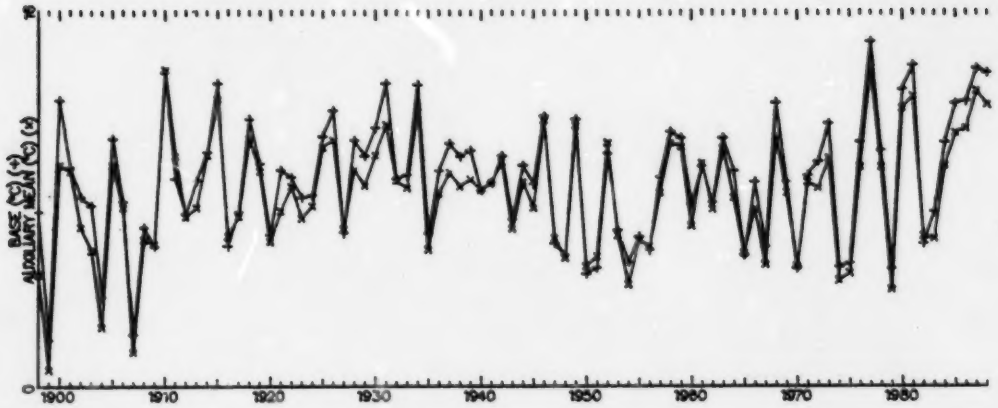


Figure 3.1 **Winter Season Maximum Temperature Series For Regina And Reference Series A (upper) And B (lower)**

REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1898 TO 1988

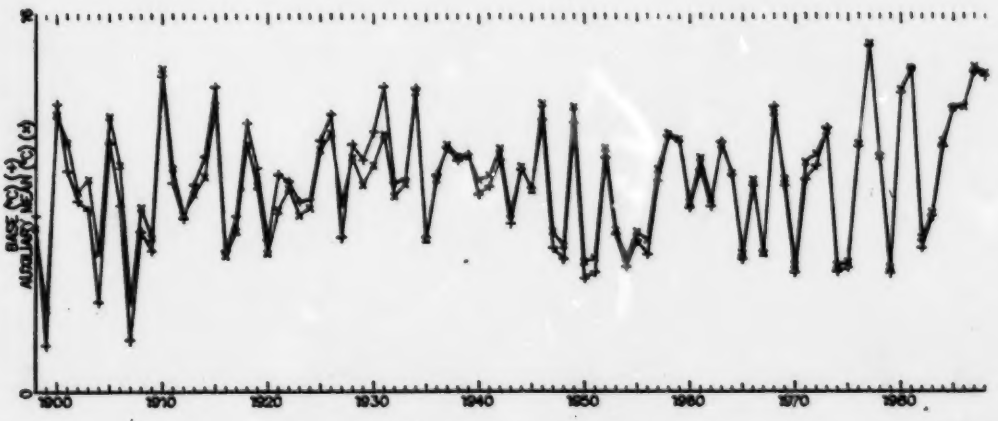
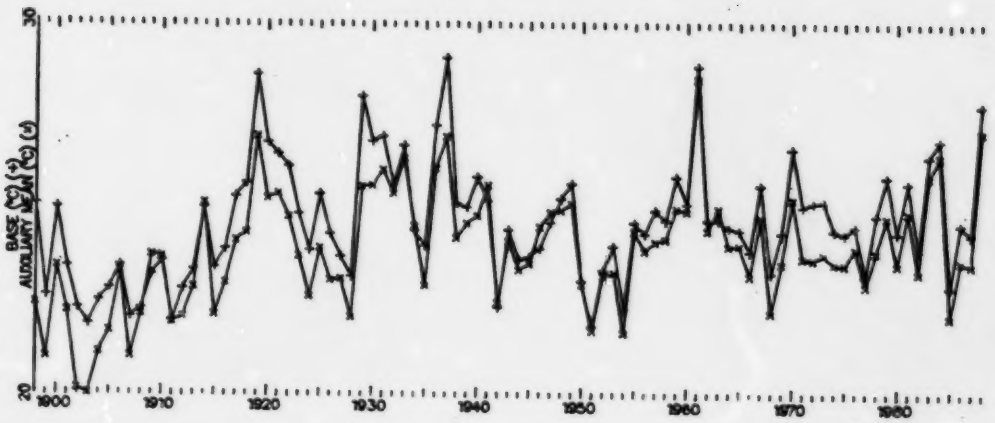


Figure 3.2 **Spring Season Maximum Temperature Series For Regina And Reference Series A (upper) And B (lower)**

REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SUMMER
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SUMMER
1898 TO 1988

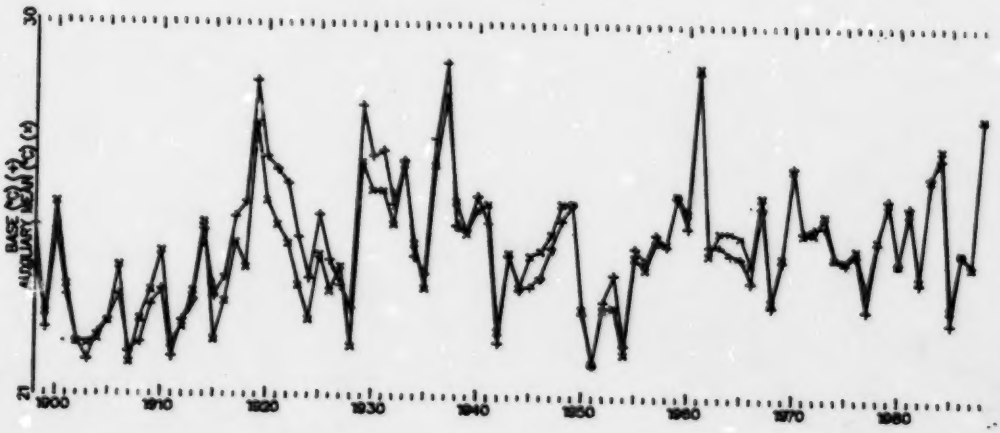
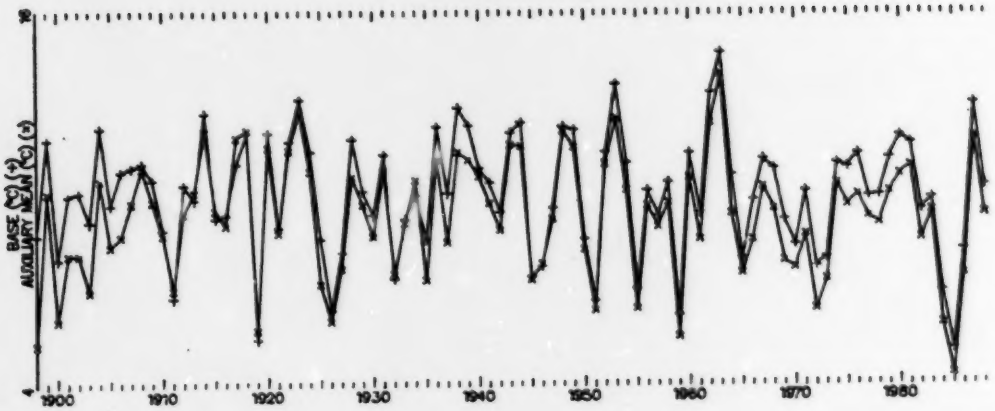


Figure 3.3 Summer Season Maximum Temperature Series For Regina And Reference Series A (upper) And B(lower)

REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1898 TO 1988

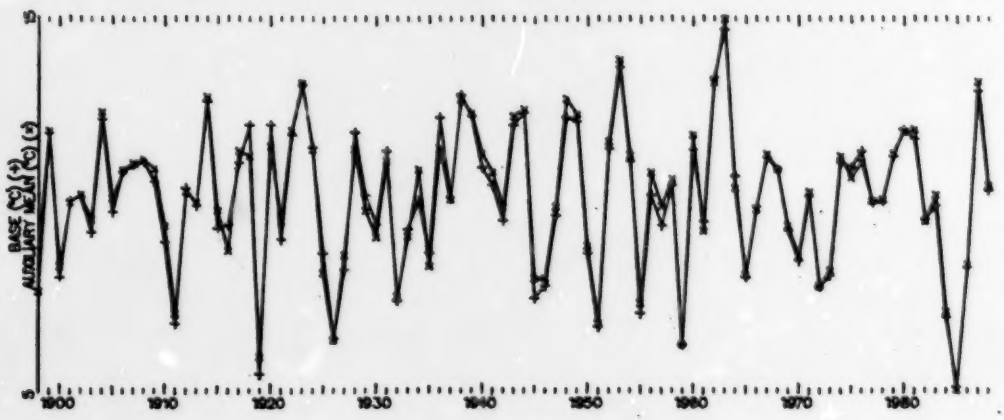
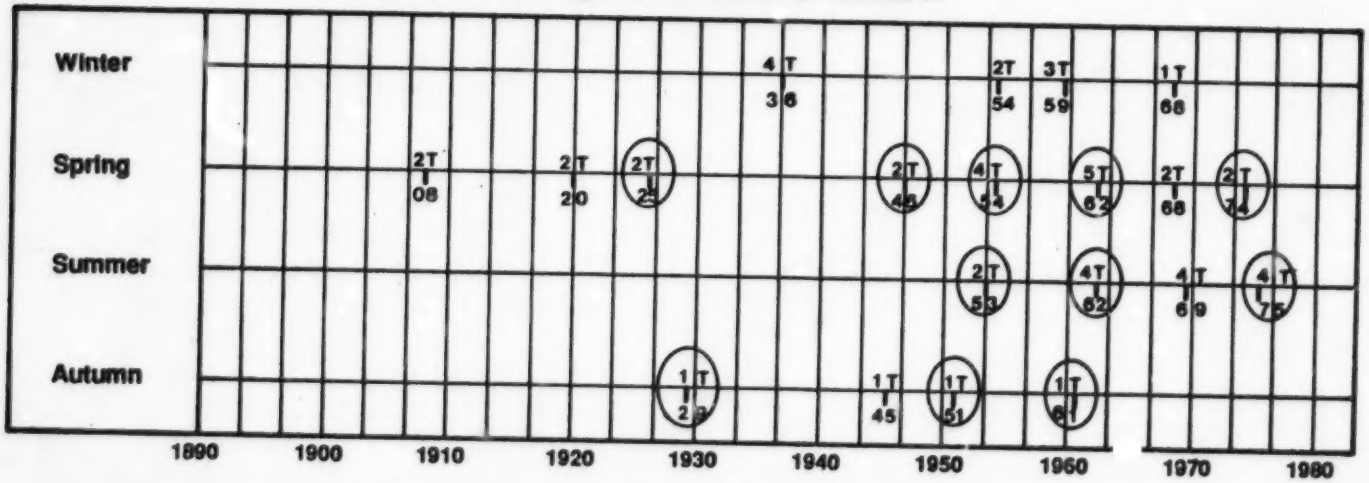


Figure 3.4 **Autumn Season Maximum Temperature Series For Regina And Reference Series A (upper) And B (lower)**

Minimum Temperature for Regina and Reference Series A



Minimum Temperature for Regina and Reference Series B

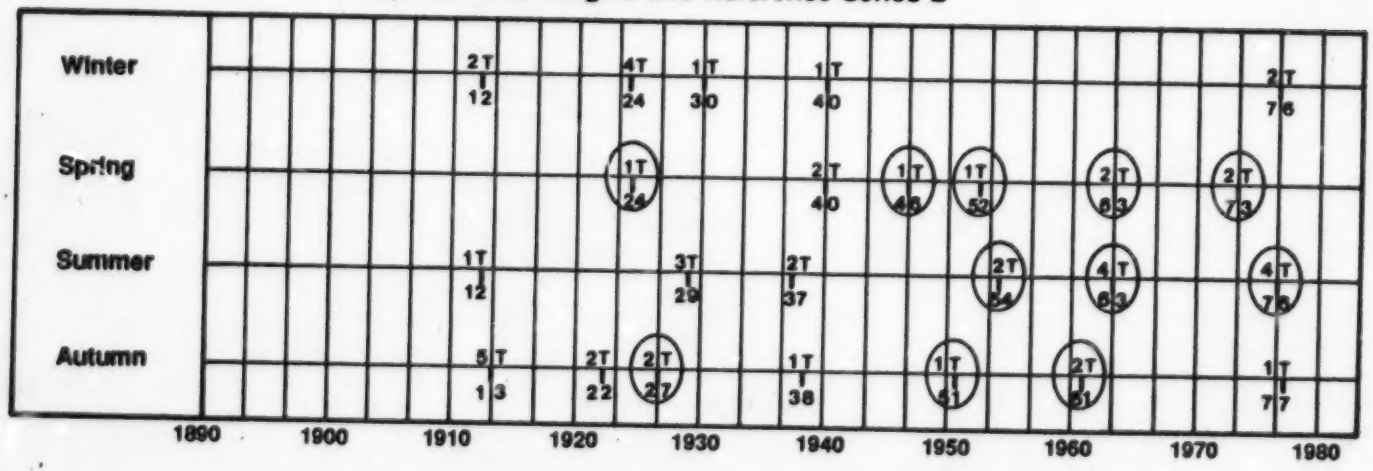
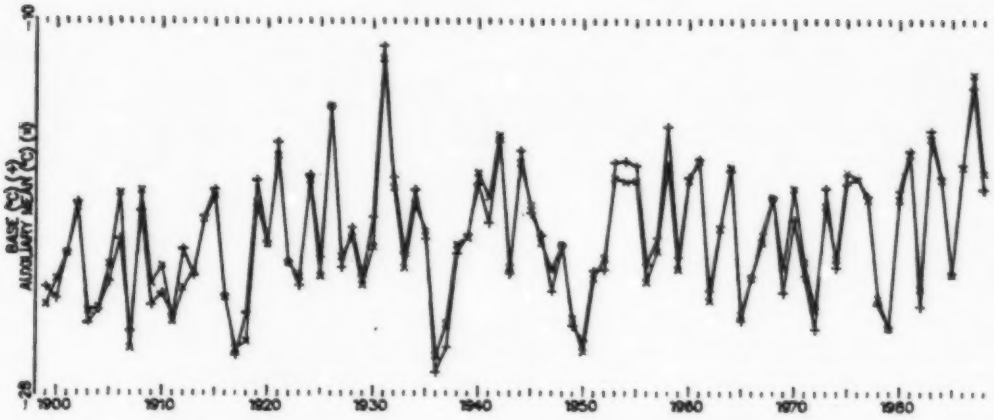


Figure 4.0 Years Identified by T-Value Exceeding the 95% Critical Limit

Notes:

1. Circled years represent "failed" test results common to both the A and B computer runs and year shown is the year in which the peak t-value occurred (e.g., 40 represents peak t-value in 1940)
2. Consecutive "failed" test results are shown above the year in which the peak t-value occurred (e.g., 2T represents two consecutive "failed" tests (i.e., two consecutive years)).

REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1898 TO 1988

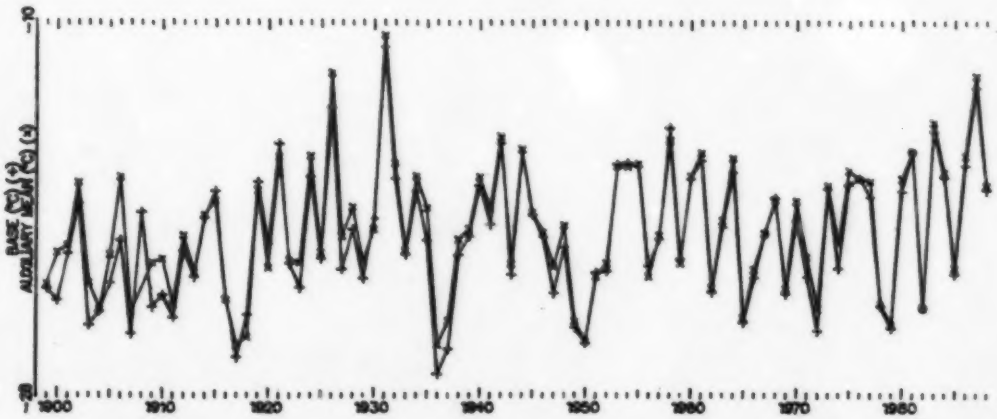
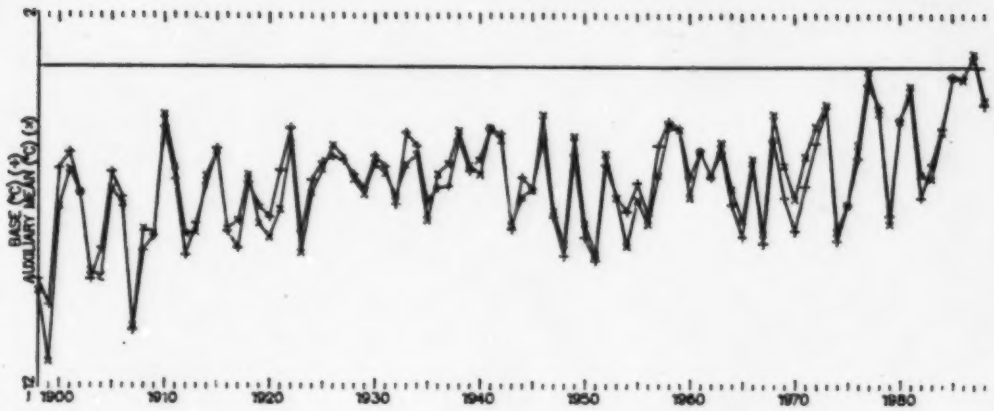


Figure 4.1 **Winter Season Minimum Temperature Series For Regina And Reference Series A (upper) And B (lower)**

REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1898 TO 1988

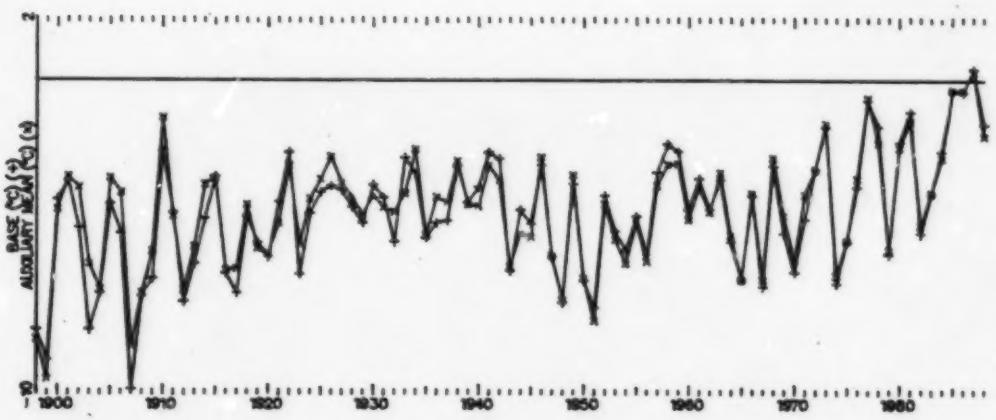
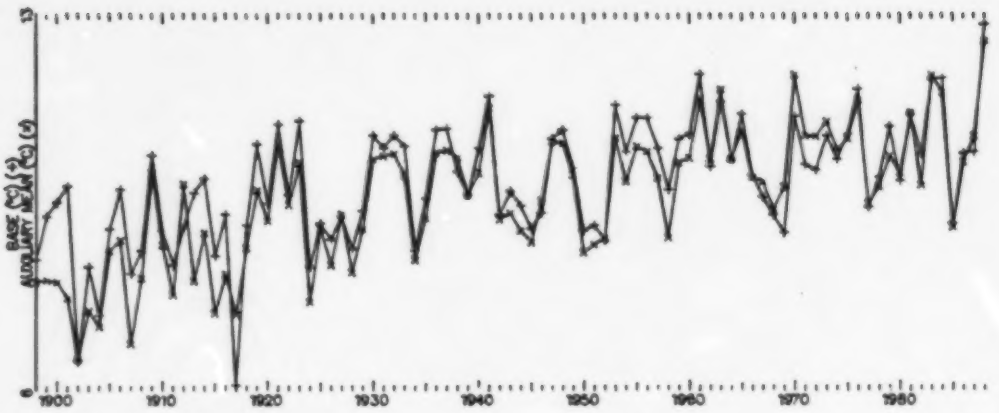


Figure 4.2 Spring Season Minimum Temperature Series For Regina And Reference Series A (upper) And B (lower)

REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SUMMER
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SUMMER
1898 TO 1988

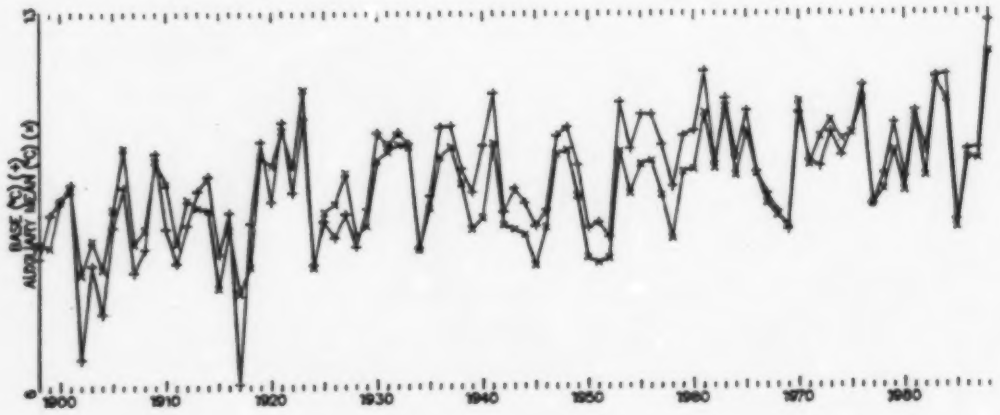
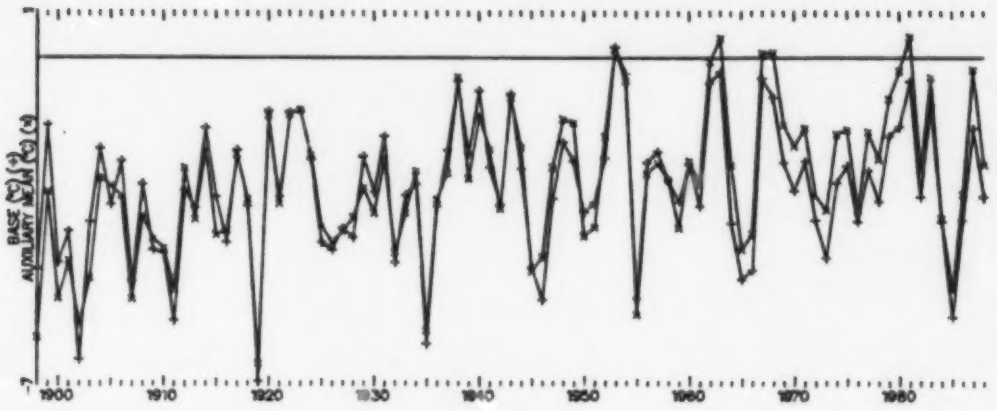


Figure 4.3 **Summer Season Minimum Temperature Series For Regina And Reference Series A (upper) And B (lower)**

REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1898 TO 1988



REGINA A, SASK AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1898 TO 1988

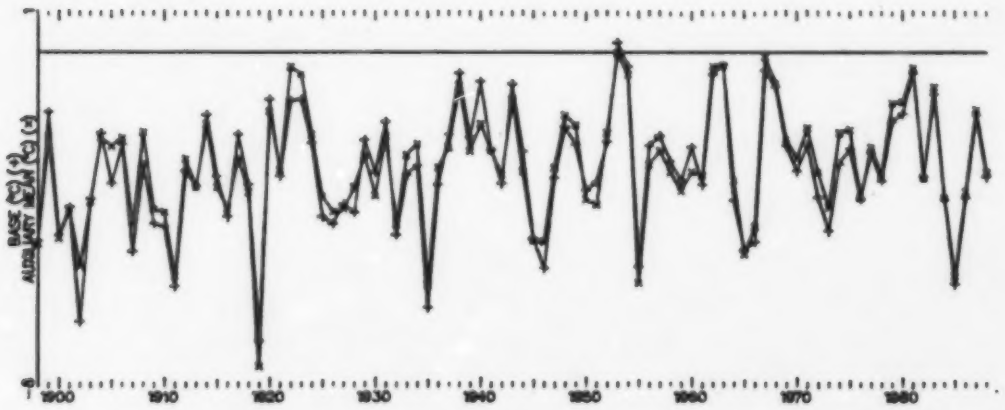


Figure 4.4 **Autumn Season Minimum Temperature Series For Regina And Reference Series A (upper) And B (lower)**

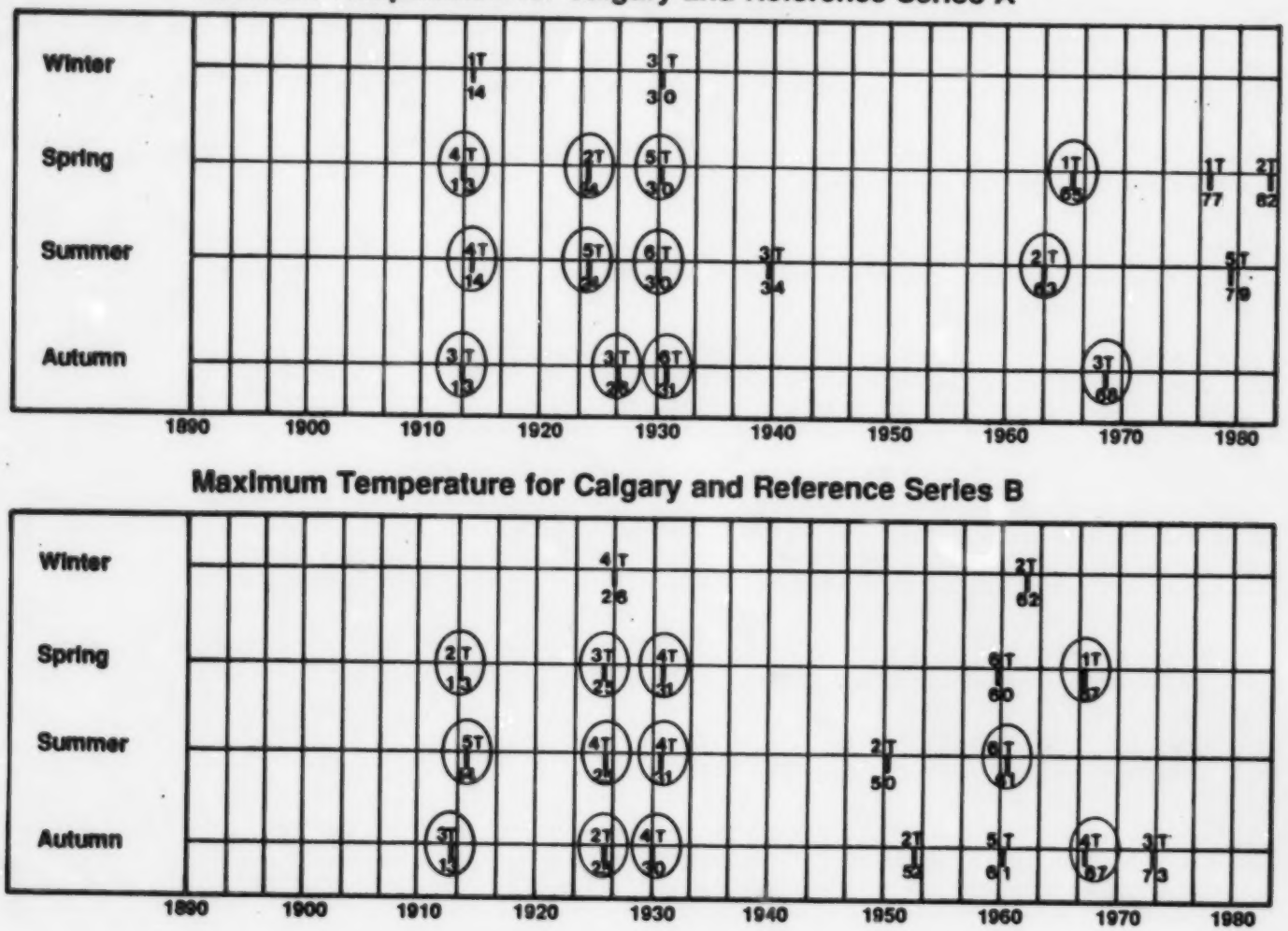


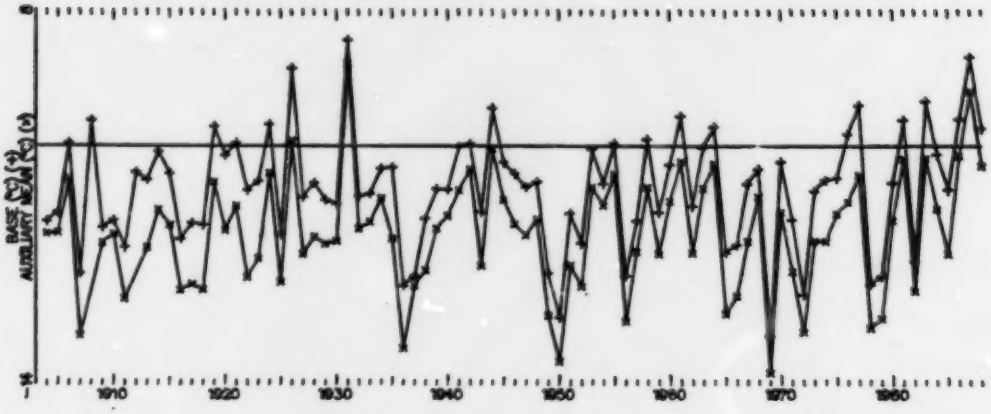
Figure 5.0 Years Identified by T-Value Exceeding the 95% Critical Limit

Notes:

1. Circled years represent "failed" test results common to both the A and B computer runs and year shown is the year in which the peak t-value occurred (e.g., 40 represents peak t-value in 1940)

2. Consecutive "failed" test results are shown above the year in which the peak t-value occurred (e.g., 2T represents two consecutive "failed" tests (i.e., two consecutive years)).

CALGARY NTL A, ALTA AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1903 TO 1988



CALGARY NTL A, ALTA AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1903 TO 1988

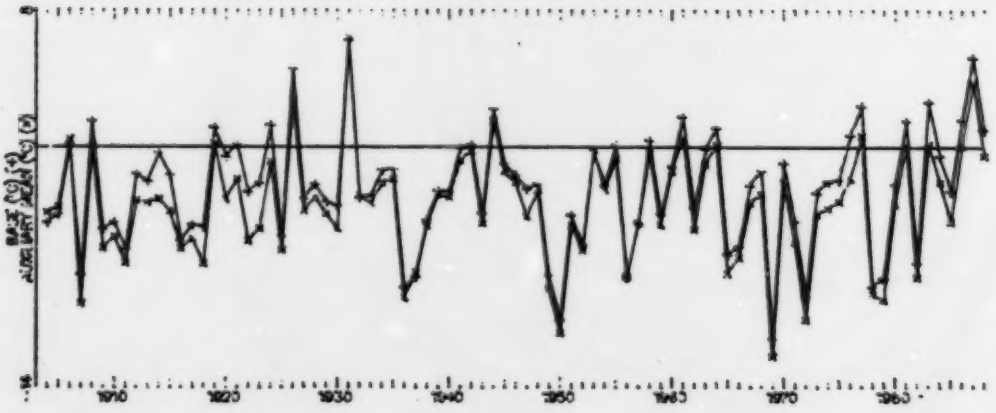
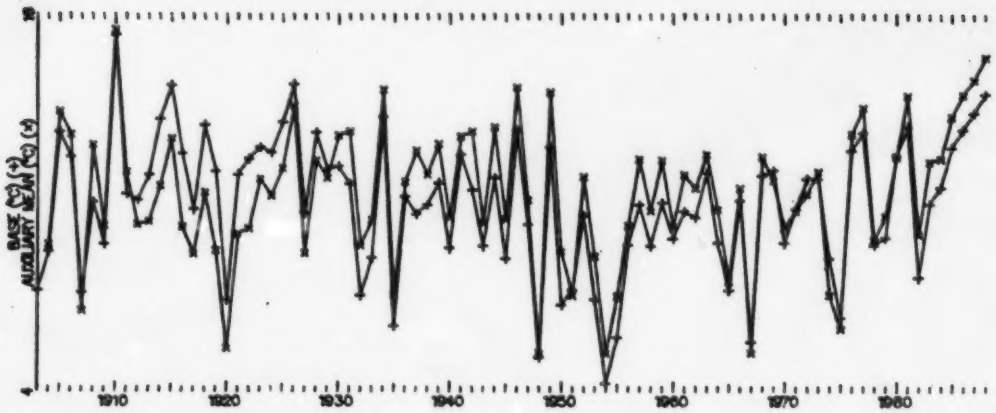


Figure 5.1 **Winter Season Maximum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**

CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1903 TO 1988



CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1903 TO 1988

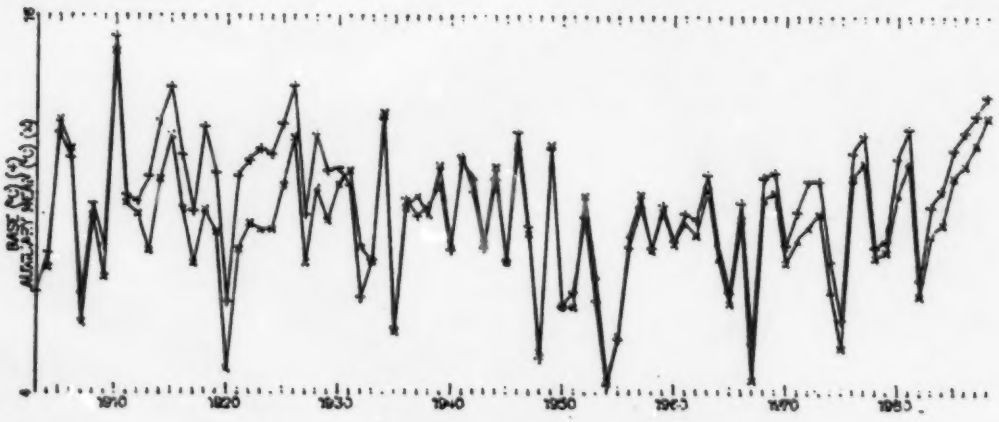
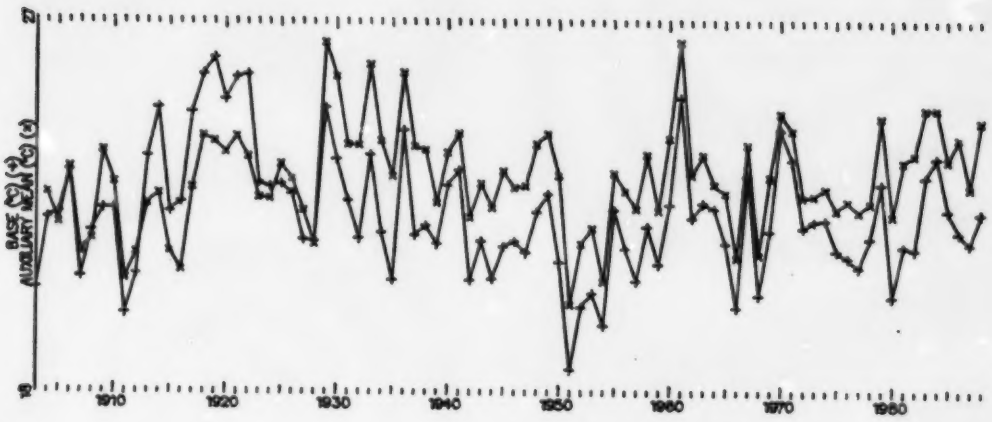


Figure 5.2 **Spring Season Maximum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**



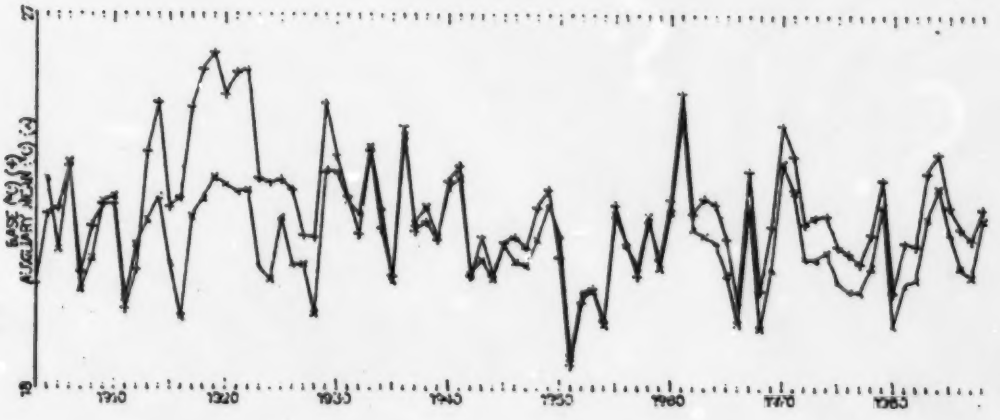
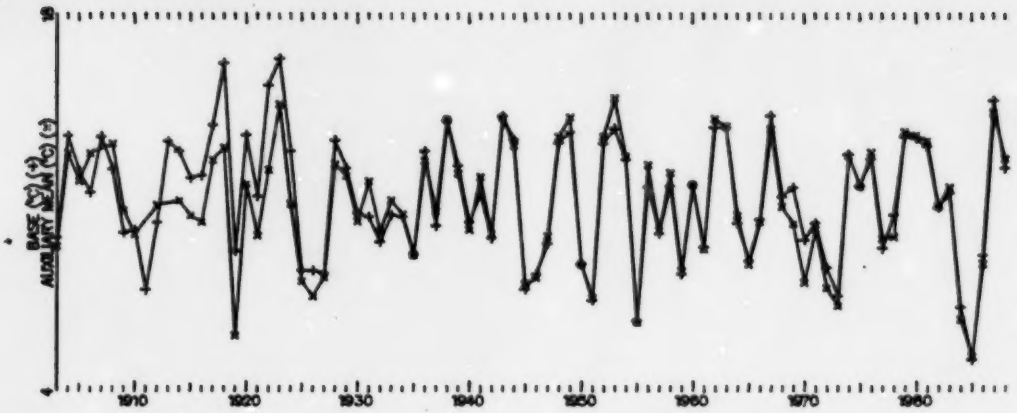


Figure 5.3 **Summer Season Maximum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**

CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1903 TO 1988



CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MAXIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1903 TO 1988

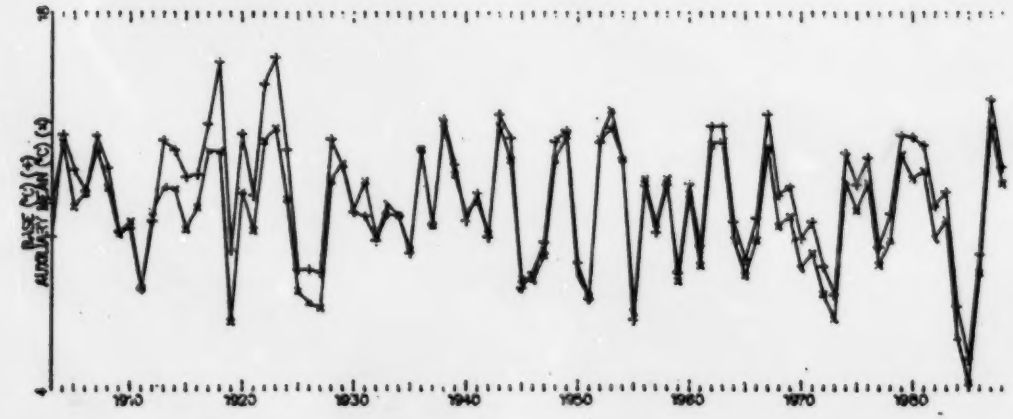
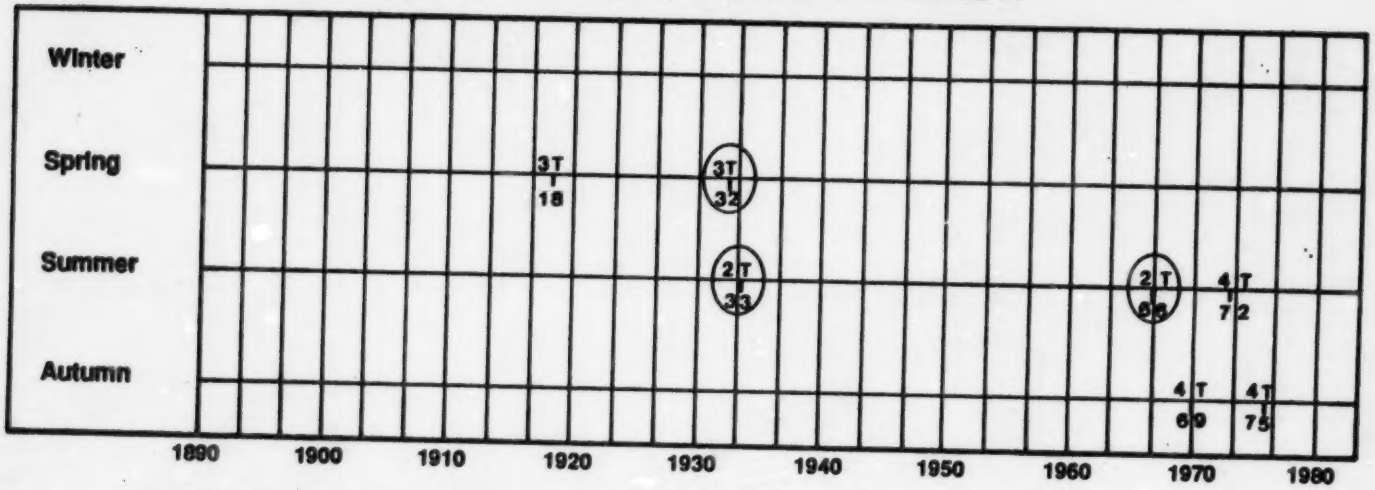


Figure 5.4 **Autumn Season Maximum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**

Minimum Temperature for Calgary and Reference Series A



Minimum Temperature for Calgary and Reference Series B

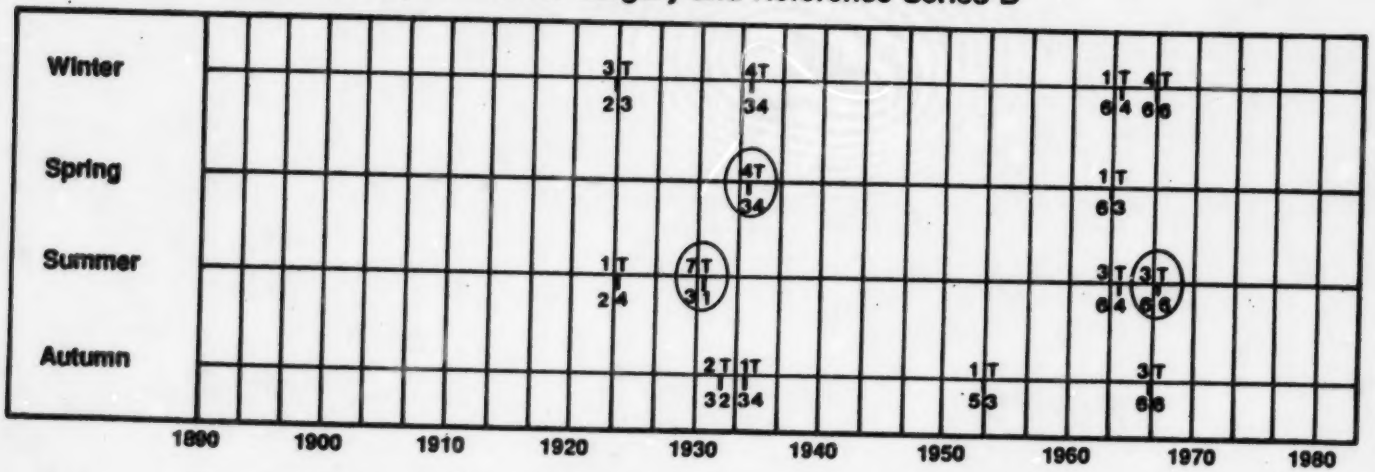


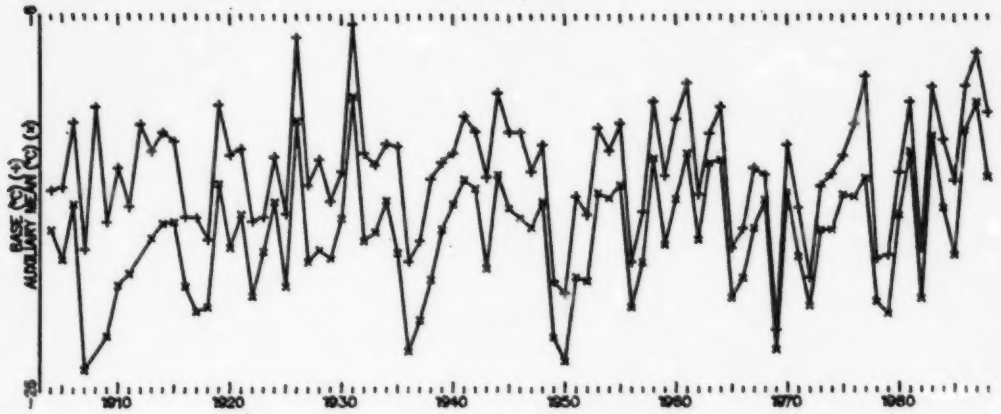
Figure 6.0 Years Identified by T-Value Exceeding the 95% Critical Limit

Notes:

1. Circled years represent "failed" test results common to both the A and B computer runs and year shown is the year in which the peak t-value occurred (e.g., 40 represents peak t-value in 1940)

2. Consecutive "failed" test results are shown above the year in which the peak t-value occurred (e.g., 2T represents two consecutive "failed" tests (i.e., two consecutive years)).

CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1903 TO 1988



CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
WINTER
1903 TO 1988

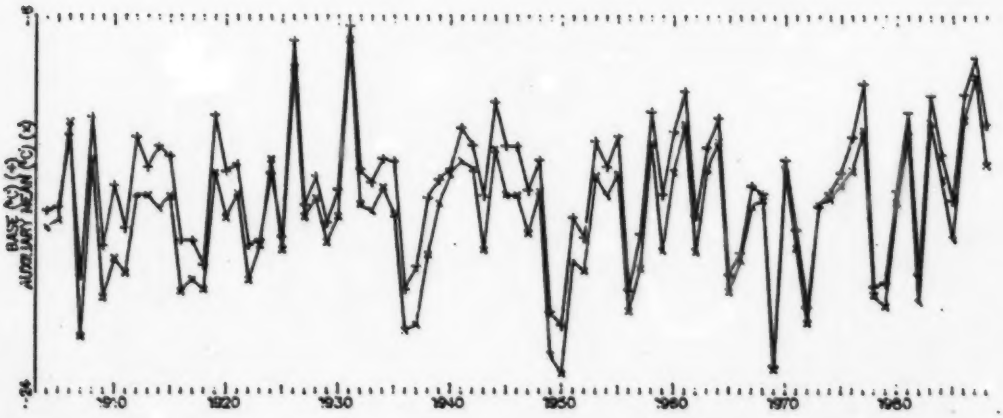
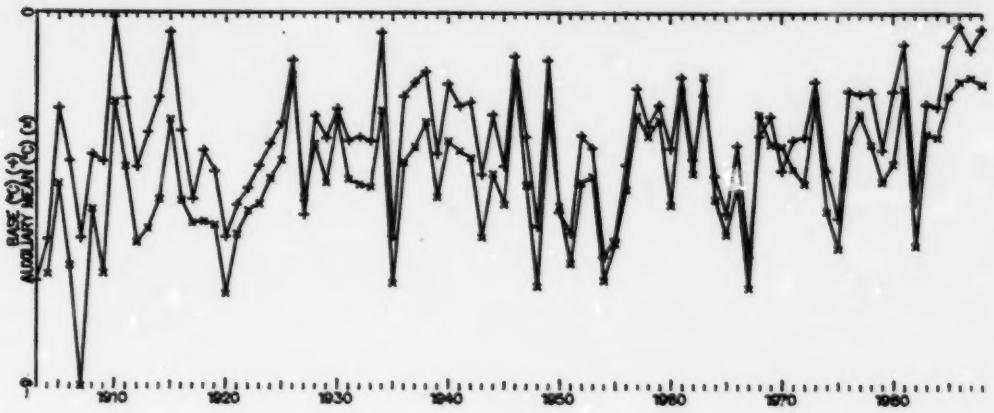


Figure 6.1 **Winter Season Minimum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**

CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1903 TO 1988



CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SPRING
1903 TO 1988

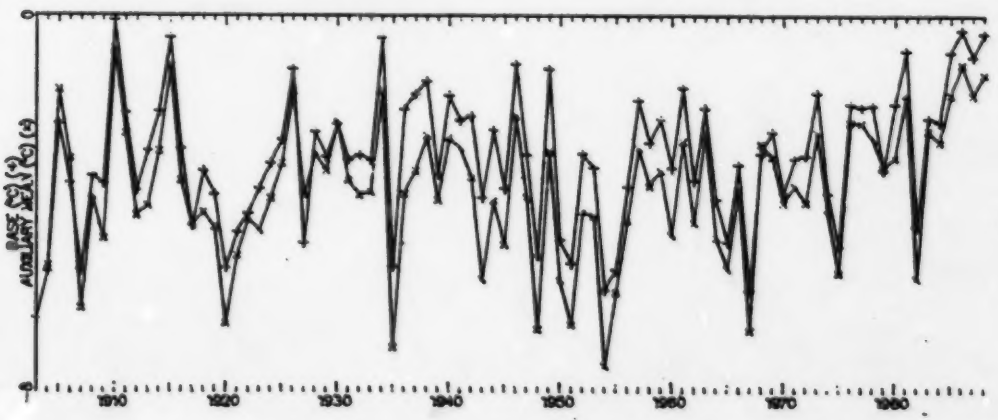
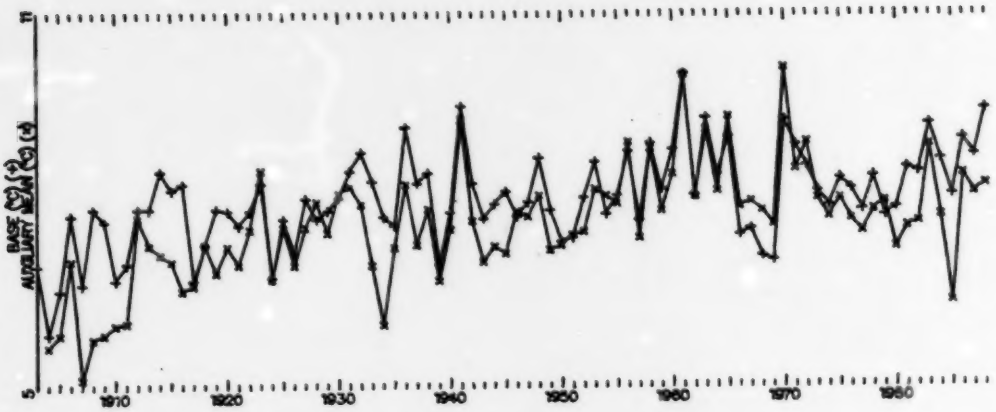


Figure 6.2 **Spring Season Minimum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**

CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SUMMER
1903 TO 1988



CALGARY NT'L A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
SUMMER
1903 TO 1988

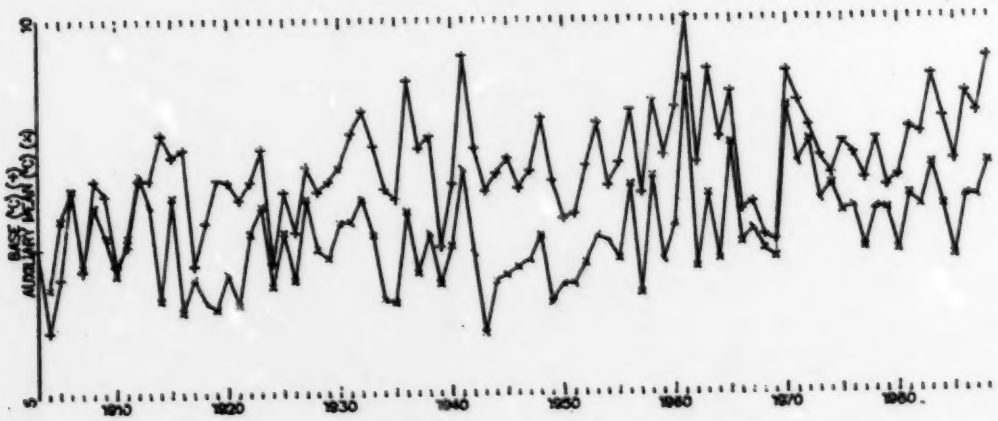
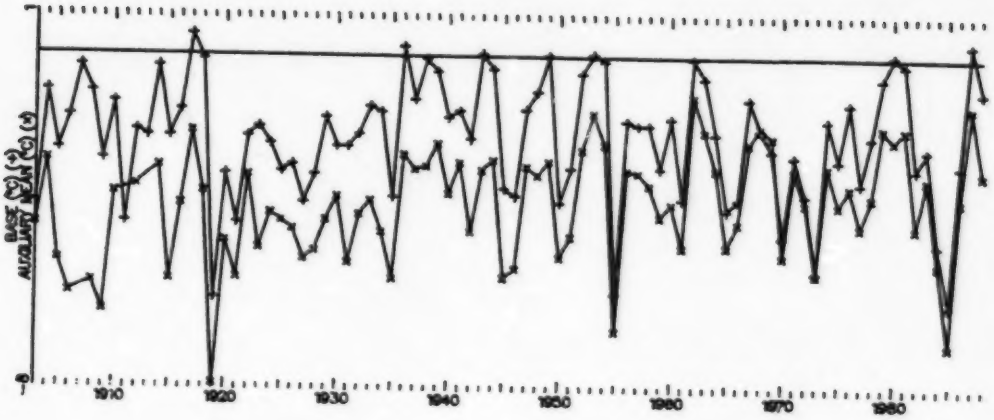


Figure 6.3 **Summer Season Minimum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**

CALGARY NTL A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1903 TO 1988



CALGARY NTL A, ALTA AND AUXILIARY STATIONS
MINIMUM TEMPERATURE
TIME SERIES OF BASE AND AUXILIARY MEAN
AUTUMN
1903 TO 1988

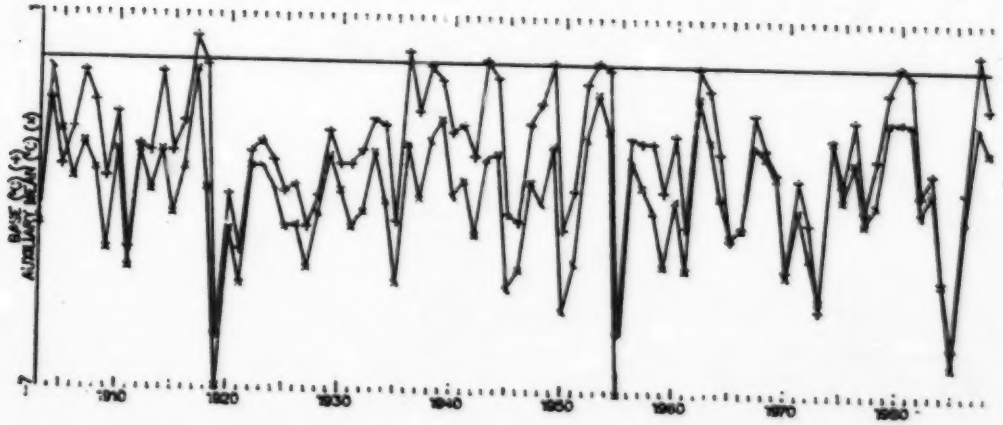


Figure 6.4 **Autumn Season Minimum Temperature Series For Calgary And Reference Series A (upper) And B (lower)**